PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

VOL. LVII.

FROM MAY 1921, TO MAY 1922.

BOSTON:
PUBLISHED BY THE ACADEMY.
1922.

The Cosmos Press
CAMBRIDGE, MASS.

Amer. Acad. of Science
94.
4-6-1923

CONTENTS.

57–1

Proceedings of the American Academy of Arts and Sciences.

Vol. 57. No. 1.—December, 1921.

THE GRID STRUCTURE IN ECHELON SPECTRUM LINES.

By Norton A. Kent and Lucien B. Taylor.

Investigations on Light and Heat made and published with aid from the Rumford Fund.

(Continued from page 3 of cover.)

VOLUME 57.

1. Kent, Norton A. and Taylor, Lucien B.— The Grid Structure in Echelon Spectrum Lines. pp. 1–18. December, 1921. $.75.

Proceedings of the American Academy of Arts and Sciences.

Vol. 57. No. 1.—December, 1921.

THE GRID STRUCTURE IN ECHELON SPECTRUM LINES.

By Norton A. Kent and Lucien B. Taylor.

Investigations on Light and Heat made and published with aid from the Rumford Fund.

THE GRID STRUCTURE IN ECHELON SPECTRUM LINES.

Norton A. Kent and Lucien B. Taylor.

Received July 7, 1921. Presented October 19, 1921.

Some years ago Nutting [1] noted a peculiar, complex structure, termed by him the "fluting" or "grid," which appeared in many echelon spectrum lines, and consisted of several fine components of different and often changing intensity. Later one of us [2] independently noted this structure. Nutting crossed the 12″ Lummer plate of the Bureau of Standards with his echelon and was apparently forced to the conclusion that the structure was real — that is, that it indicated an actual discontinuity of emission in the source.

Proceeding on the assumption of reality, the writers attempted a solution of the problem using Liλ 6104 which, although known to be a spectroscopic doublet, offered peculiar advantages in that the grid was extremely brilliant, well-marked and persistent.

Apparatus.

The apparatus used consisted of:—

Two echelons: No. 1, made by Porter, 30 plates, each 14.76 mm. thick, step 1 mm., aperture 31.0 by 33.0 mm.; No. 2, made by Petitdidier, 30 plates, each 23.29 mm. thick, step 1 mm., aperture 31.0 by 35.5 mm.

The Bureau of Standards 12″ Lummer plate kindly loaned by Dr. Stratton.

A Hilger Lummer plate — length 131 mm., width 14.5 mm., depth 4.827 mm.

A Hilger constant deviation prism spectroscope combined with an echelon as in Figure 1a; also a separate Hilger spectroscope with another echelon spectroscope as in Figure 1b. The achromatic lenses of both echelon spectroscopes are of about 50 cm. focal length and 5 cm.

---

1 Astrophys. Jour. 23, pp. 64 and 220. 1906.
2 Kent, Proc. Am. Acad. XLVIII, No. 5. Aug. 1912.

aperture; each echelon bed rotates on an axis at its center; the Hilger micrometer is fitted with one fixed and two movable cross-hairs as shown in Figure 2.

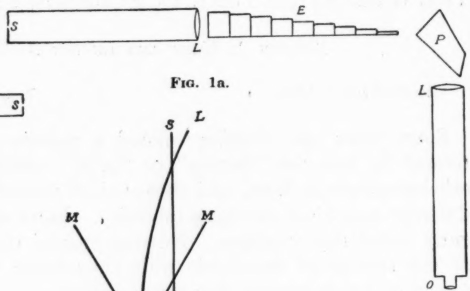


Fig. 1a.

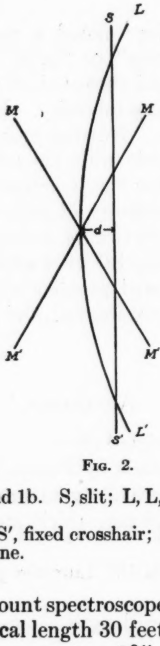
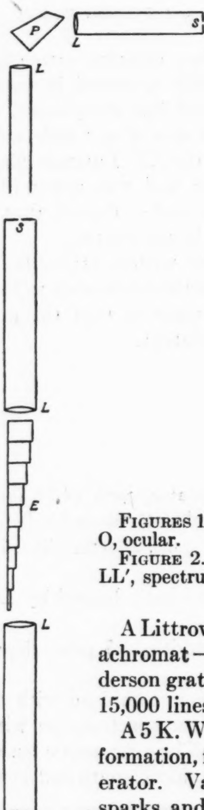


Fig. 2.



Figures 1a and 1b. S, slit; L, L, lenses; E, echelon; P, prism; O, ocular.

Figure 2. SS', fixed crosshair; MM', MM' movable system; LL', spectrum line.

Fig. 1b.

A Littrow mount spectroscope consisting of a Petitdidier achromat — focal length 30 feet, aperture 6″; and an Anderson grating — aperture $3\frac{3}{4}''$ vertical by 5″ horizontal, 15,000 lines per inch, used in the third order.

A 5 K. W. transformer, 110 to 30,000 volts ratio of transformation, fed by a 60 cycle Holtzer-Cabot 4.5 K. W. generator. Various large induction coils capable of giving 6″ sparks and operated by a rotary mercury break and an electrolytic interrupter, had proven insufficient.

A vacuum arc of construction as indicated in Figure 3.

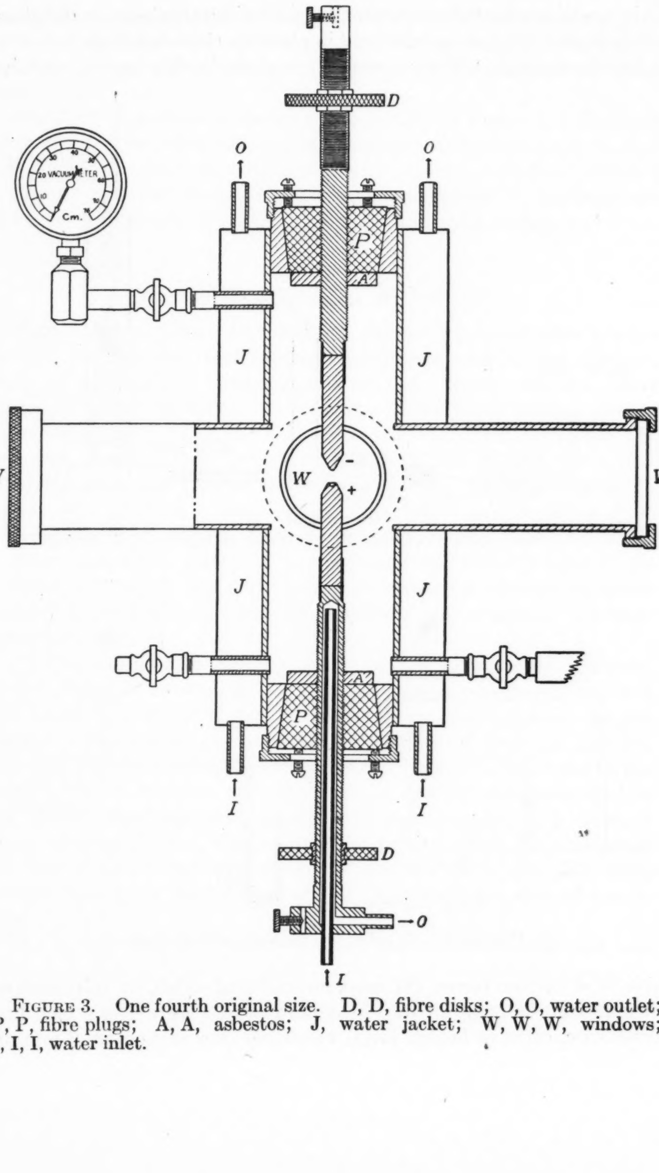


FIGURE 3. One fourth original size. D, D, fibre disks; O, O, water outlet; P, P, fibre plugs; A, A, asbestos; J, water jacket; W, W, W, windows; I, I, I, water inlet.

This was also adapted to pressures of several atmospheres as the glass windows and fibre plugs were held in place by threaded rings.

Quartz vacuum tubes — even pyrex glass having proven unsuit-

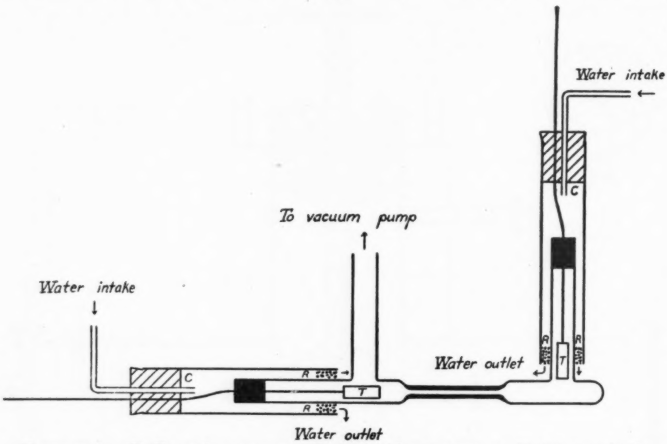


FIGURE 4. C, C, cork stoppers; R, R, rubber sponges; T, T, terminals.

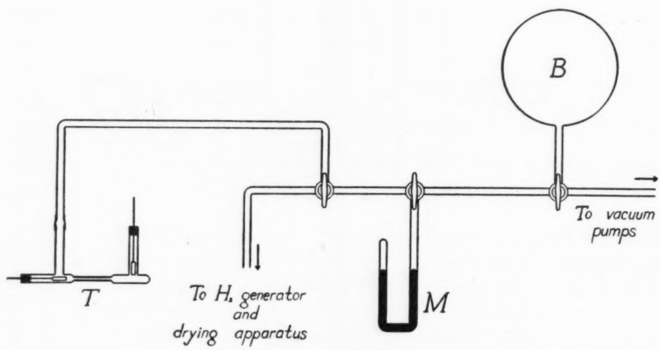


FIGURE 5. T, tube; M, manometer; B, bulb.

able — of various forms, the most successful of which, for salts such as lithium chloride, proved to be that shown in Figure 4 in which fine brass wire, often in helical form, was fitted into brass caps, 6 mm. in

diameter, and sealed in with De Khotinsky cement, each joint being cooled by a water jacket. The salt is shoved into the capillary by a wire and the tube will run many hours without refilling. It may be used end on as well as side on. The capillaries varied from 2 to 0.5 mm.

Auxiliary apparatus as shown schematically in Figure 5. The bulb B, prevented too rapid changes in pressure. The system was washed out with hydrogen from a Kipp generator, dried by sulphuric acid and a calcium chloride tower. The mercury manometer, M, indicated the pressure — generally from 8 cm. to a fraction of a millimeter.

Procedure and Certain Results.

Both Lummer plates were each in succession crossed with echelon No. 1. In each case, with a carbon arc soaked with lithium chloride, both at atmospheric pressure and in a moderate vacuum, there appeared a pattern which, at this stage of the investigation, seemed to indicate that the grid was real. The following facts, (1) to (6), are, however, clearly not in accord with this conclusion, and prove conclusively that this curious structure is due to the phenomenon of "secondary maxima" observed by Stansfield [3] and resulting from successive reflections from the surfaces of the echelon plates, producing a Fabry and Perot system in the region of the primary light of the echelon. (1) to (3) deal with some of the criteria of echelon secondary maxima given by Stansfield. These criteria are, in essence, indicated below by italics.

(1) The width of Liλ 6104, given by an open carbon arc at atmospheric pressure, as seen in the Littrow grating, using a narrow slit, was found to be about 0.25 t. m. when echelon No. 2 showed the grid plainly. The suspicion, therefore, was confirmed that the line was too wide for the echelon, the difference between the adjacent orders, being about 0.26 t. m. In the case of Janicki's observation [4] of Hg. λ 5461, Nutting's work on lines of many elements, and the work of one of us on the zinc lines as given by arc and spark, the indications are that with all lines for which the echelon shows the grid, their breadth is so great that the use of this instrument is not at all justifiable.

The writers then proceeded to study the structure from this new

---

[3] Phil. Mag. (6) 18. 383. 1909.
[4] An. der Phys. Vol. XIX, p. 36. 1906.

standpoint, considering the primary line of width approximately 0.25 t. m., and not as formerly, one of the grid components itself.

These components are indeed, in this sense, each *narrower than the primary maximum* — 0.25 t. m.— the grid components, all of them now regarded as secondary maxima, being only about 0.05 t. m. in width in echelon No. 2.

(2) The curvature of one of the mercury yellow lines was compared with that of a grid component in λ6104. By stopping down the echelon spectroscope slit, a line of definite length was observed, and by setting the stationary cross-hair of the filar micrometer upon the ends of the image, and the movable system upon its center, the horizontal distance, d, Figure 2, from the ends of each line to its center were measured. It was found that the *curvature of the component is* about 25% *greater than that of the primary line.*

(3) With a small mirror, set at 45°, over the lower half of the echelon spectroscope slit an argon vacuum tube and the lithium arc were observed at the same time. The relative motion of the grid components in λ6104 and a nearby argon line were then studied as the echelon was rotated. The *primary* argon *line moves about one-half as fast as the grid components.*

Quantitative measurements of the relative displacements were later made with Zn λ4810. A quartz vacuum tube was fitted with coiled brass wire leads and brass terminals, exhausted, filled with hydrogen to 10 or more cm. pressure and then gradually exhausted to 1 mm. or less. The zinc lines given by the brass wire leads appeared very sharp, steady and brilliant. With λ4810, as thus produced, was compared the "gridded" line of a cored carbon arc at atmospheric pressure, in which small pieces of zinc had been placed, the small mirror arrangement allowing simultaneous observation of both sources. Upon rotation of the echelon the grid components rushed by the narrow tube line. To measure the relative speed a plane mirror was attached to a side of the echelon case. The image of an illuminated slit in a piece of cardboard was formed by a lens upon a distant scale after reflection from the mirror. The echelon was set near the $\theta = 0$ position. A reading of the position of the slit image on the scale was taken when the tube line lay upon the fixed hair of the filar micrometer. The echelon was then rotated until the slit image moved about 2 cm. The displacement of the tube line was then measured by the movable cross-hair system. A similar series was then taken with a grid line. The ratio of the displacements was 3.6 : 6.4 or about 1 : 2.

(4) The echelon was removed and the ocular focussed on the prism

image of a line. Replacing the echelon shortened the focus for a true narrow echelon image by about 0.6 mm. The focus for the grid components of the same line was 0.7 mm. shorter yet — the light forming the grid had traversed the echelon plates more than once.

(5) Although the grid components are generally very well defined (the minimum being "deep"), it is a difficult matter, with a fluctuating source such as an open arc, to obtain accurate measurements. The grid spacings appear to vary slightly at different stages. When the grid is complete the spacing is regular and, within the limits of error of measurement is equal to one fifth the distance between the orders. This was proven as follows:— A quartz tube having merely coils of fine brass wire as terminals gave extremely fine zinc lines. Echelon No. 2 was set in double order condition and Δo, the difference between the two orders, measured for $\lambda 4810$ (see Table I). Then the grid was measured as given by a 3 ampere open carbon arc. Three distinct series of readings were taken. Then the tube was again used. The accuracy of an individual setting was about 0.2% in Δo and about 5% in Δg. It thus appears that in this region, at least within 2%, $\Delta o = 5 \Delta g$. The focus of the instrument was, of course, not changed, the difference between that for primary and secondary maxima being so slight that distances between the components of the grid are not appreciably affected.

TABLE I.

Distances are measured in divisions of the micrometer head. Each Δo distance given is the mean as calculated from four settings; each Δ_g from two. Settings were made on the six centrally situated grid components.

Δo for Zn λ 4810		Δg for six grid components.						
		1–2	2–3	3–4	4–5	5–6	Mean	Mean of Means
22.60	Mean	4.3	4.8	4.6	4.8	4.7	4.6	
	22.58	4.8	4.4	4.6	4.8	4.1	4.5	4.6
22.50		4.3	5.0	5.0	4.3	4.7	4.6	
$22.58 \div 4.6 = 4.9$ or $\Delta o = 4.9\, \Delta g$								

A similar series for Zn $\lambda 6362$ gave $\Delta o = 27.65$ and $\Delta g = 5.6, 5.9, 5.5, 5.6, 5.4$: mean = 5.5. Hence $\Delta o = 5.0\, \Delta g$.

(6) The structure given by both echelons is the same. That is, there are five secondary maxima for every primary maximum. Δg for Hydrogen $\lambda 6563$ is 0.061 t. m. for instrument No. 2, while for No. 1 it is about 0.096 t. m., which again is another fact fatally inconsistent with the existence of a definite discontinuous emission in the source.

With this evidence at hand the writers then attempted to clear up the results of the crossed dispersions. The source previously used was hardly adequate. By removing the soft core of the lower carbon it was possible to feed copiously into the arc a strong LiCl solution. Greater brilliancy and steadiness were obtained. The results were unmistakably in accord with the facts given in (1) to (6) above. Figures 6a and 6b indicate the structure observed. These will be

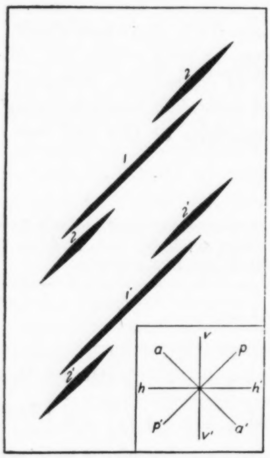


Fig. 6a.

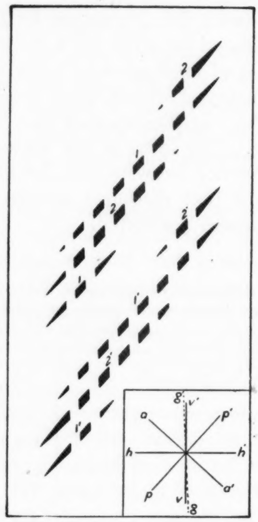


Fig. 6b.

Figure 6a. Li $\lambda 6104$ with crossed Lummer plate and echelon. Grid not indicated. λ_1 and λ_2 in single and double order condition respectively.

Figure 6b. Li $\lambda 6104$ as in Fig. 6a. Grid shown. λ_1 and λ_2 both between single and double order condition.

discussed in full below (see page 16). When one component of the spectroscopic doublet is in double and the other in single order condition three lines appear; when both are in a condition between single

and double order there are four lines. It is probable that these four lines, under conditions of inferior illumination, were interpreted as four separate and true lines. It is unfortunate that at first the only line available for study was a doublet. With this latter and better source a zinc chloride solution gave λ4810 sufficiently strong. The crossed dispersions prove it to be a simple, though broad, single line when the echelon alone shows the grid.

Further Results: Characteristics of the Grid.

(a) From numerous observations upon Li λ6104 and Zn λ4810, as developed by various sources, such as vacuum tubes and arcs (on 110 and 220 volt D.C. circuits and from 1 to 20 amperes) under high, normal and low pressure, in which the cross-hairs of the filar micrometer were set successively upon the true, narrow, lines given by the tube and the grid components given by the arc, it is quite certain that the grid is built up approximately as follows:— Suppose that in a hypothetical grating of resolving power and dispersion equal to that of the echelon, a line which is at first very narrow, e.g., 0.025 t. m., gradually becomes less monochromatic, owing to changing conditions in the source, and appears as represented diagrammatically by the small letters *a* to *e*, Figure 7. Four cases must be discussed as shown in Figures 7 to 10, respectively.

Case I:— The echelon in double order condition gives successively images *A* to *E*. When the line is very narrow the echelon shows it as such, in *A*. Similarly for a line of width, Δg — the width of a grid component or an intergrid distance — it is shown as in *B*. When of width $3\Delta g$, the echelon shows no change, *C* appearing as *B*; for, at *m*, the primary and secondary action together give a decided minimum. When the line has a width, as in *d*, the echelon shows a triplet, *D*, and when of width as in *e*, or greater, the grid is complete — five grid maxima, 1 to 5 and 6 to 10, for each maximum, such as 3 and 8, which a narrow line would give; four maxima, 4 to 7, between the double order positions, 3 and 8, of such a narrow line. For a given position of the echelon these grid components do not, in forming, move very much, if at all: they come up in situ. There exists an *apparent* motion, in and out, which is probably due to the changing width of the primary line, which may not at all times be such as to complete the entire width of a grid component.

Case II:— When the position of the echelon, its temperature and the wave length of the line observed, result in the central grid minimum

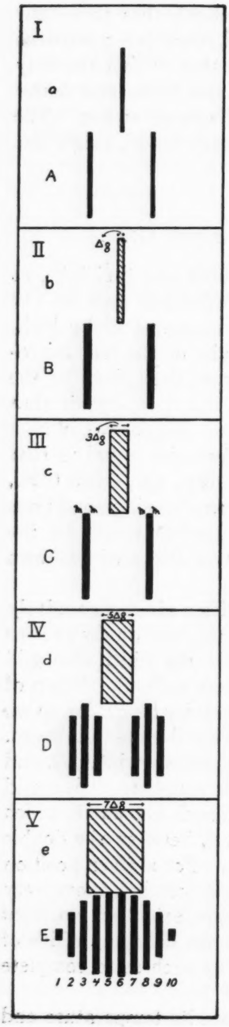


FIG. 7.

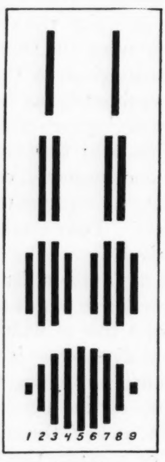


FIG. 8.

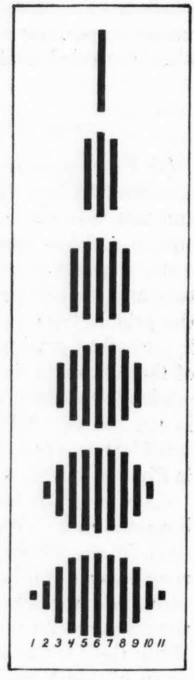


FIG. 9.

FIGURE 7. Case I: Echelon in double order condition and a grid maximum coincident with the primary maximum.

FIGURE 8. Case II: Echelon in double order condition and a grid minimum coincident with the primary maximum.

FIGURE 9. Case III: Echelon in single order condition and a grid maximum coincident with the primary maximum.

occurring in the position of the narrow tube line, as in Figure 8, for a double order condition of the echelon, there are nine or even eleven components when the grid is strong. Note that the grid components 2, 3, 7, 8, which at first are very brilliant when the grid is "young," grow weaker, 2 and 8 often being so faint that it is difficult to make accurate micrometer settings upon them.

CASE III:— The treatment is the same for a single order condition of the echelon, as in Figure 9 which shows a triplet, quintuplet, or, with neighboring parts of adjacent orders, even as many as eleven components.

CASE IV:— Here a grid minimum coincides with the primary maximum and the grid components are as shown in Figure 10.

The above statements explain why an originally narrow line, as its width increases, may appear, as it actually does, a triplet or quintuplet, as in Figures 7 and 9, or may, as it were, "reverse" and then quadruple, as in Figures 8 and 10. Actual reversal as shown by the grating probably occurs much later in the history of the line. (See page 15.)

Further, if a line be intrinsically unsymmetrical, shading off to the red for instance, the secondary action masks an early stage of broadening, and the left grid line, 2, forms as in *A*, Figure 11. Line 3, as in *A′*, then comes up as 2 strengthens.

(b) The grid begins to disappear and the line gradually becomes broad and structureless when the primary line exceeds $2\Delta o$ in width, Δo being the distance between two adjacent orders. This was determined as follows:— Using as narrow a slit as possible, a low power ocular and a mm. scale, an eye estimate was made of the breadths of various portions of an arc line shown by the grating. These were reduced to t. m. The same source was viewed simultane-

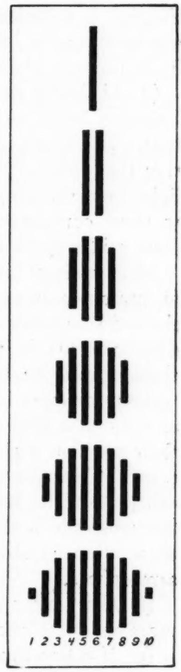


FIG. 10.

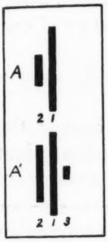


FIG. 11.

FIGURE 10. Case IV: Echelon in single order condition and a grid minimum coincident with the primary maximum.

ously by echelon No. 2. For Zn λ4810 three components of the grid exist when the grating shows a line 0.12 t. m. broad. Δo for λ4810 = 0.155 t. m. $\frac{3}{5} \times 0.155 = 0.09$ t. m. which compares favorably with 0.12 t. m. The complete grid exists when the line is 0.3 t. m. or 2Δo broad and the image begins to pass into a structureless line at 3Δo. Similarly for Li λ6104 a full and well-marked grid exists at a line width about 0.2 to 0.5 t. m. or Δo to 2Δo (as here Δo = 0.25 t. m.). The grid is poorly marked above about 2Δo and is gone at 3Δo.

(c) Numerous lines in the spectra of Na, Hg, Fe, Mg, Cd, Ca, Sn, Pb, and Bi, developed by an open carbon arc, show the grid whenever the line is sufficiently broad — rendered so by introducing more of the substance or increasing the current; also by increasing the capacity in the case of a spark.

(d) Li $\lambda\lambda$6708 and 6104, Zn $\lambda\lambda$4810, 4722 and 4680, also Hg λ5461 (mercury being fed into the lower cored carbon) show by their behavior that a line which is too broad will appear structureless in the echelon, that the center of the core of an arc may show the grid complete while light from the wings of the image gives a simple structure of but one to three components. With a sufficient amount of vapor the complete grid may be obtained even at low pressure.

(e) A study of Zn λ4810, from an arc in the vacuum or pressure tank, at pressures from 2 cm. of mercury to about three atmospheres, showed that moderate changes of pressure do not produce measurable displacements in the grid components, but merely alter somewhat their relative intensities, shifting the maximum over one or two components or even bringing up new ones. This of course means that, as long as a grid exists, the components do not change appreciably their position with changes of wavelength as small as 0.015 or 0.020 t. m.[5] Their position is affected more strongly by the position of the echelon and its temperature. Similarly, the grid components of the spectroscopic doublets Li $\lambda\lambda$6708 and 6104 developed in vacuum tubes show intensity shifts with changes of pressure over the range of one atmosphere.

(f) The "end on" position of a vacuum tube will generally show a more complete grid than that "side on."

(g) If a line broaden unsymmetrically with increase of current the maximum of intensity will shift. Those components which are just being formed show an apparent motion outward as the number of

---

[5] According to Humphrey's and Mohler's results for Zn, the pressure shift reduced to λ 4000 is 0.057 t. m. for twelve atmospheres.

components increases, the first step resembling a narrow reversal as in Figures 8 and 10 or a central fixed line with two moving wings as in Figures 7 and 9. But the writers feel that this apparent motion is due to the fact that each grid component is not formed *in toto* at once: the part which lies nearest the center of the system is formed first. Certain it is that this apparent motion ceases abruptly when the component has reached a position which is one grid distance from its neighbor. If the source be an arc, many rapid fluctuations in intensity occur.

(h) Although the resolving power of the grating (225,000 in the third order) is far below that of the echelon (about 750,000 for λ6100 for echelon No. 2) it is hard to reconcile the images given by the two instruments on any other assumption than that the grid is due to secondary action.

To throw further light on the problem, Li λ6104, given by a vertical carbon arc soaked with LiCl, was viewed simultaneously by echelon and grating. Table II gives a summary obtained from various arrangements.

TABLE II.

|||| indicates the grid; ■ a broad structureless line; | a narrow unreversed line, or one very slightly reversed; ▮▮ a broad and strongly reversed line.

<table>
<tr><th>Arrangement</th><th>Sign of upper pole</th><th>Pole soaked with solution</th><th>Echelon shows</th><th>Grating shows</th></tr>
<tr><td>1</td><td>+</td><td>+</td><td>At + pole ||||</td><td>|</td></tr>
<tr><td></td><td></td><td></td><td>" – " ■</td><td>▮▮</td></tr>
<tr><td>2</td><td>+</td><td>–</td><td>" + " ||||</td><td>|</td></tr>
<tr><td></td><td></td><td></td><td>" – " ■</td><td>▮▮</td></tr>
<tr><td>3</td><td>–</td><td>–</td><td>" – " ■</td><td>▮▮</td></tr>
<tr><td></td><td></td><td></td><td>" + " ||||</td><td>|</td></tr>
<tr><td>4</td><td>–</td><td>+</td><td>" – " ■</td><td>▮▮</td></tr>
<tr><td></td><td></td><td></td><td>" + " ||||</td><td>|</td></tr>
</table>

Therefore which pole is soaked makes no difference, nor does it matter which pole is above. The region near the + pole generally shows the grid in the echelon, that near the – pole a broad structureless line. The grating always gives a narrow unreversed line or one very slightly reversed where the echelon shows the grid, and a strongly reversed line where the echelon shows no structure. Thus the grid does not result from conditions which produce a reversed grating line.

With Li $\lambda 6708$, which usually appears widely reversed in the grating, the grid is more difficult to obtain in the echelon, while with Na $\lambda 4972$ — given as an unreversed line by the grating at either edge or centre of the arc image — the echelon shows the grid at both edge and centre.

(i) We are now in a position to discuss in detail Figures 6a and 6b. These were obtained with the 131 mm. Lummer plate set between the collimator and prism of Figure 1b and crossed with echelon No. 2. The source was that described on page 10: the arc current being from 10 to 25 amps. The plate dispersed vertically, the echelon horizontally. Both figures are drawings based on visual filar micrometer measurements, a single cross hair being moved successively along the axes, *vv'* (vertical), *hh'* (horizontal), *aa'* (across the structure) *pp'* (parallel to it), as shown below the two figures.

Two Lummer plate orders are shown in each figure, the primes distinguishing these. The numerals indicate the two components of the spectroscopic doublet, the breadth along axis *aa'* their approximate relative intensity. λ_1 is the weaker line, λ_2 the stronger in both figures — λ_2 being the component of longer wavelength.

In Figure 6a λ_2 is in double order condition; in 6b both λ_1 and λ_2 are between double and single order. The echelon grid structure is not indicated in Figure 6a: in 6b its *approximate* position is shown. It was difficult to observe at the ends of the lines and so is not there indicated: it is slanted at an angle of about 2.4° (see *gg'* in Figure 6b) with the vertical. The slant of the lines themselves as well as that of the grid changes with the positions of both plate and echelon: further, the grid slant is not due to the curvature of the echelon image. This may throw some light on the disappearance of the grid at a breadth of line greater than $2\Delta o$. For, as the echelon action alone is given by the projection, on the *pp'* axis, of the grids of the lines λ_1 and λ_2, it is evident that lack of coincidence owing to slant would tend to obliterate the grid altogether, this indicating that two broad lines, the centers of which lie as far as 0.1 t. m. apart (the $\Delta\lambda$ of the two components of Li $\lambda 6104$), may not give coincident grid structures; or, in other words, the grid maxima do not (for any one position and temperature of the echelon) necessarily fall together. This is not inconsistent with shift of intensity for small changes of wavelength (0.015 to 0.020 t. m.) as noted on page 14. Shift of intensity and position probably both enter with change of wavelength of the center of gravity of a primary echelon image.

These two figures show that the grid is unquestionably a secondary

echelon action. Otherwise the regions between lines 1 and 2 would have been filled in with a structure along axis aa' similar to that along pp'.

With an echelon alone we have obtained only the weaker component of Li λ6104 as a single narrow line. We plan to cool the tube with liquid air, thus sharpening the stronger component so that it will no longer suffer the secondary action, to which the small satellite is probably due.

(j) We have no record of having observed in either echelon any ungridded line of width greater than Δg. Either there exists (1) a very narrow line, (2) an irregular series of such, as, for instance, in the yellow mercury lines, (3) a line of width Δg, (4) a series of such (the grid more or less complete) or (5) a broad, structureless image covering between one and two orders. And it appears extremely probable that the "reversal" of the main component of Hg λ5461, noted under certain conditions by several observers and often noticed by us, may be modified by the entrance of secondary action due to the excessive breadth of this component.

(k) The retardation producing the primary maxima of a narrow line is proportional to $n-1$, while that of the light undergoing secondary action is proportional to $3n-1$. Thus the difference in retardation in case of the two actions bears the ratio to the retardation of the primary of $\frac{2n}{n-1}$, which is a function of n alone. The value of $\frac{2n}{n-1}$ varies from 5.50 for λ6563 to 5.37 for λ4341 in echelon No. 2; and from 5.48 to 5.35 respectively in No. 1. Since echelons are generally made of substantially the same kind of glass, any two having equal separation of primary orders will have equal separation of secondary maxima, because this separation is the same fractional part of the separation of the orders; but the values of Δg in t. m., varying with the dispersion, will, of course, differ in different instruments.

We cannot state just why $\Delta o = 5\Delta g$. The measurements given above indicate that this is so within the limits of experimental error for both the violet and red regions.

It would be interesting to assemble an echelon under water, press the plates together and allow the superfluous water to drain off. This process might vastly reduce the secondary action. If successful Canada balsam might be substituted for water thus producing a more permanent instrument. We plan to try this experiment shortly.

Conclusion.

Summarizing the above results, we may state that the evidence is entirely against the existence of a discontinuity of emission in the source. The grid is due to a secondary action of the echelon which enters when the line under investigation is not sufficiently monochromatic. This means that the previous work of one of us[6] must be considered as of small value and also that an explanation of the apparent complexity of structure obtained by Nutting[7] can be found in secondary action.

The results obtained emphasize the fact that when an echelon is used to measure small wavelength differences, great care must be taken to obtain the lines so narrow that their width is less than $\frac{1}{5}\ \Delta o$, else secondary action may enter to cut off an edge of a line and thus give a false intensity-maximum position.

We must record our appreciation of the help rendered by various student assistants, especially Messrs. Greenleaf and Risga. We are also indebted to Dr. Lucy Wilson for her skilful aid during part of this research and to our assistants, Miss Pearson for mathematical work in connection with the calculation of the constants of the echelons, and Mr. Gilman for making the sketches accompanying this article.

We wish also to thank sincerely the Rumford Committee of the American Academy for numerous grants which made possible the purchase of the main pieces of apparatus used in this investigation.

6 Proc. Am. Acad., Vol. XLVIII, No. 5. Aug. 1912.
7 Astrophys. Jour., XXIII, pp. 64 and 220. 1906.

Physical Laboratory, Boston University,
May, 1921.